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Progress Report on the Recharge Area Delineation of Hanging Lake, A National Natural Landmark within the White River National Forest, Colorado

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Introduction

The Ozark Underground Laboratory, Inc. (OUL) has conducted over 50 recharge area delineations of significant springs, caves, and karst features for the U.S. Forest Service, National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, and several state natural resource agencies over the last 30 years. The recharge area of a spring or cave is the land area that contributes water to that feature. The OUL was contracted by the National Forest Foundation in 2021 to conduct a recharge area delineation for Hanging Lake on the White River National Forest (WRNF) in Colorado.

Hanging Lake is a National Natural Landmark recognized for its national significance and outstanding characteristics as a karst feature. It is also a heavily-visited attraction for locals and tourists. The lake has formed from massive travertine deposits created by the dissolution of the Leadville limestone by groundwater that then resurges in the East Fork of Deadhorse Creek, a tributary to the Colorado River on the southern edge of the White River Plateau in Glenwood Canyon. The travertine deposition has formed a series of dams in the canyon, the largest of which has impounded spring water to form a scenic lake perched high above the canyon floor. This is Hanging Lake.

Travertine deposition occurs when water that is super-saturated with dissolved limestone loses its ability to keep the limestone in solution, resulting in the deposition of crystalline calcium carbonate. This process is very common in caves and creates well-known cave formations such as stalactites, stalagmites and flowstone, collectively called speleothems. However, travertine deposition above ground requires a unique combination of physical and chemical conditions and travertine features as large as those forming Hanging Lake are rare and quite extraordinary.

The Grizzly Creek Fire severely burned a large area in the vicinity of Hanging Lake in 2020. The subsequent burn scar poses significant threats to the integrity of Hanging Lake. Surface effects such as debris flows and sediment transport after storm events have resulted from the loss of vegetative cover on the burn scar. These processes can have substantial consequences on the surface. Debris flows threaten the structural integrity of the travertine formations at Hanging Lake and can also have detrimental effects on the lake's water quality. Sub-surface effects of the fire and changes in the chemical processes driving travertine deposition are more uncertain. The complex chemical and hydrological relationships between terrestrial vegetation, groundwater chemistry, and travertine deposition could be profoundly altered by the effects of the wildfire. The first step to understanding and addressing these threats is to identify where the water in Hanging Lake originates.

This progress report briefly summarizes the field work and key findings from the first phase of groundwater tracing efforts by the OUL in 2021.

2021 Field Season

OUL staff had originally planned field work on the White River National Forest in August of 2021. In late July, shortly before the planned work, several torrential storm events caused catastrophic debris flows in Glenwood Canyon. These repeated debris flows ultimately caused the extended closure of Interstate 70 through Glenwood Canyon, which made the field work planned for August impossible. Field work was postponed until late September. In the weeks leading up to the field work, OUL staff coordinated with multiple members of the Colorado Cave Survey as well as staff from the WRNF and Jim Baichtal of the Tongass National Forest, Alaska to gain as much knowledge and background information on the issue as possible. A literature review of the geology, hydrology, and known karst features of the White River Plateau and surrounding areas was also conducted by OUL staff.

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On September 27, 2021, OUL staff arrived in Eagle to meet with Forest Service staff from the WRNF and members of the Colorado Cave Survey at the Eagle City Park. During the meeting, team members provided input to OUL staff on conditions in Glenwood Canyon and on the White River Plateau. The team also discussed potential sites for tracer dye introductions and sampling stations, safety considerations, logistics, and ways to communicate with the public about the study. With significant logistical support and field assistance from Forest Service personnel, OUL staff established 11 dye sampling stations, conducted sampling for background fluorescence at each station, and conducted three tracer dye introductions during the period of September 28th – September 30th.

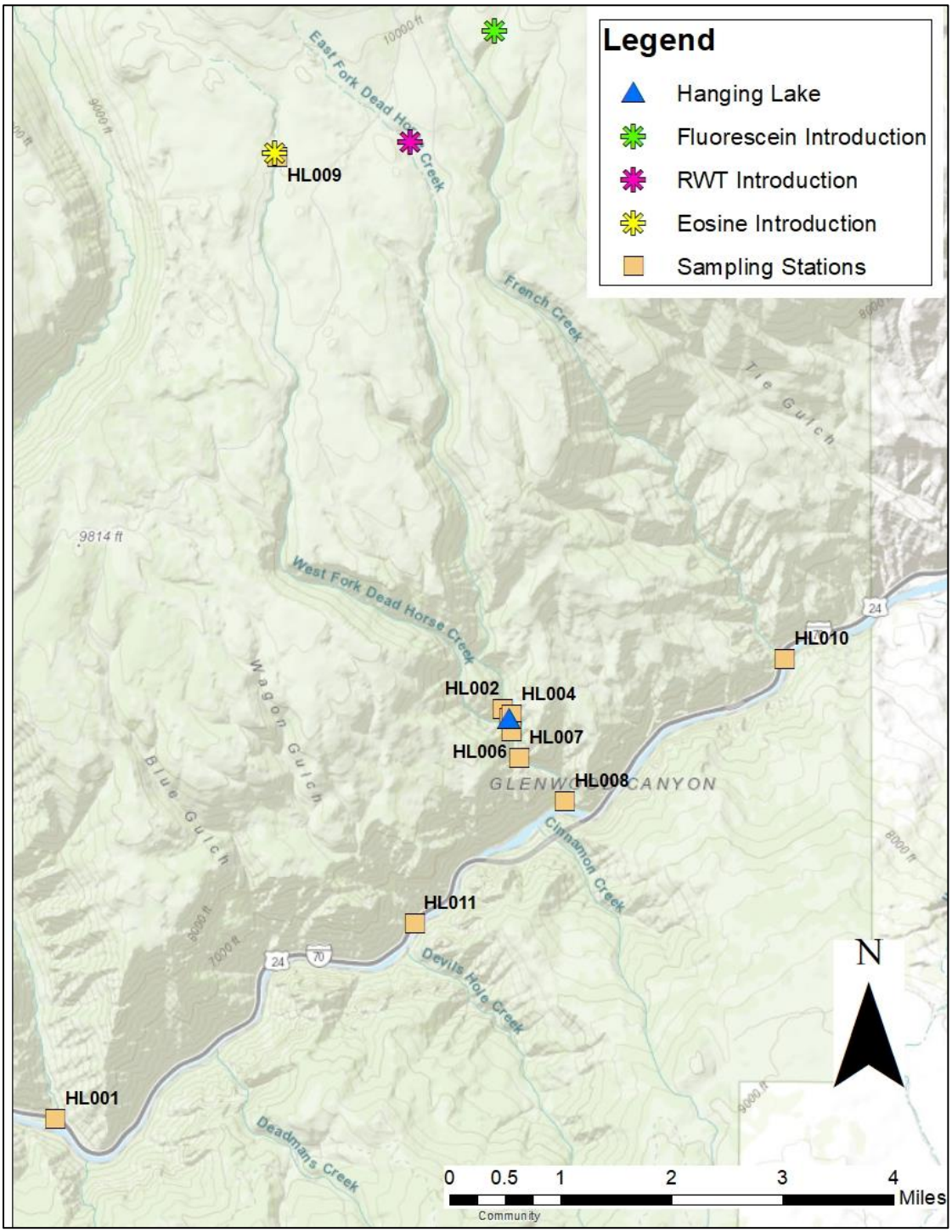
Three fluorescent tracer dye introductions were made during the 2021 field visit. Figure 1 shows all dye introduction sites and dye sampling station locations. The first trace used six pounds of fluorescein dye mixture introduced into the East Branch of French Creek near the terminus of FS Road 604. Stream flow at the time of introduction was approximately 5 gallons per minute and flow entered the groundwater system within 100 feet downstream of the introduction site.

The second dye trace used 10 pounds of eosine dye mixture introduced into the West Fork of Deadhorse Creek upstream of the Wagon Gulch Road crossing. This tracer dye was introduced as a dry set, meaning no water was present in the stream at the time of introduction. The dye was placed so that future stream flow would mobilize the dye and transport it downstream.

The final dye trace used 12 pounds of rhodamine WT (RWT) dye mixture introduced into the East Fork of Deadhorse Creek approximately ½ mile downstream of the Wagon Gulch Road crossing. This tracer dye was also introduced as a dry set, similar to the eosine trace.

Despite the 500-year storm flow events that preceded the field work in July, the month of September was very dry on the southern end of the plateau. Two of the three dye introductions were dry sets, meaning no water was available to carry the dye at the time of introduction. This placed reliance on precipitation events occurring after OUL's departure, or winter snowfall, to mobilize the dye for the tracing effort. The fluorescein trace in the French Creek drainage did involve flowing water, however the flow was minimal relative to the size of the project area. The flow conditions under which the three tracer dye introductions were made, combined with the late season and impending freezing temperatures on the plateau, led OUL staff to expect that any dye detections would most likely occur in the spring of 2022, when melt water from the snowpack would generate flow in the streams draining the plateau.

Figure 1. Dye introduction locations and sampling stations for the Hanging Lake traces conducted in September of 2021. Due to the large scale of the map, not all sampling station labels in the vicinity of Hanging Lake are visible.



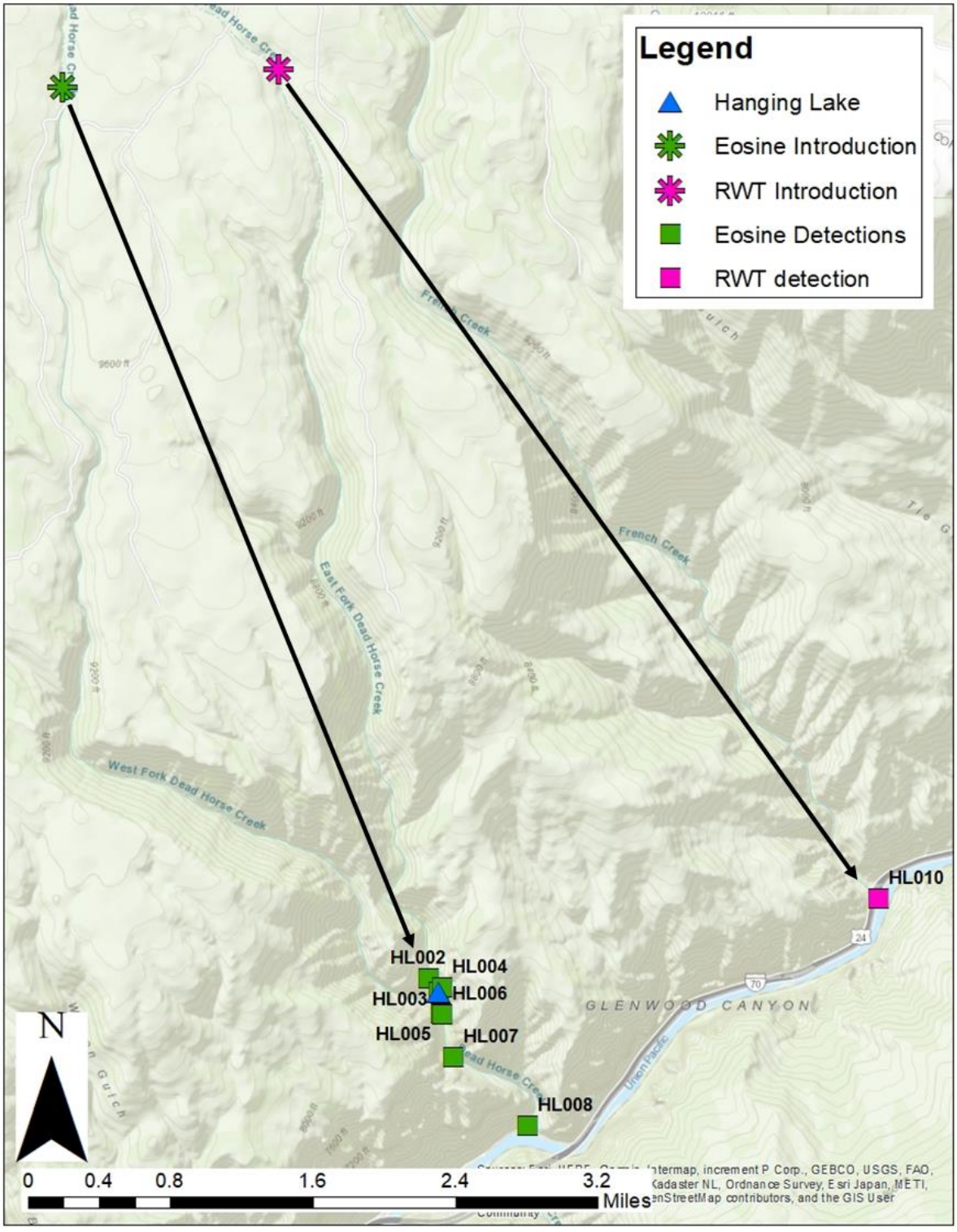
Dye sampling stations consisted of at least two activated carbon samplers secured in locations where they would adsorb fluorescent tracer dyes from the water. Carbon samplers were in place for at least a week, or longer, between sampling events. When carbon samplers were collected, a grab sample of water was also collected. Forest Service staff conducted six rounds of sample collections between October 7 and November 30, 2021. After November 30, winter conditions prevented any further sampling until the spring of 2022. Samples were sent to OUL's analytical lab in Protem, Missouri for analysis. No dye was detected in any of the samples collected in the fall of 2021.

Forest Service staff resumed sampling on March 23, 2022. Sample collections from March 23 and April 28 were received at OUL's analytical lab on May 11, 2022. Similar to the samples received in the fall, the early spring samples did not have any detectable fluorescent tracer dyes. Another batch of samples collected by Forest Service staff arrived at the OUL on June 9th. These samples were collected during the period of May 5 through June 2, 2022. During this one-month period of sample collection, significant stream flow was observed in all of the drainages being sampled. Analysis of the latest round of samples sent to the OUL finally produced positive dye detections at several sample stations.

Figure 2 shows positive dye detections and groundwater flow paths for the Hanging Lake traces conducted in September of 2021. Eosine dye introduced into the West Fork of Deadhorse Creek was detected below Spouting Rock (HL002) and in Hanging Lake (HL003 and HL004). The straight-line distance between the eosine introduction site and Hanging Lake is approximately 5.5 miles with an approximate elevation change of 2,520 feet. These detections are the result of a groundwater connection between the upper reaches of the West Fork of Deadhorse Creek and the springs that supply water to Hanging Lake, as there is no surface connection between the West Fork of Deadhorse Creek and Spouting Rock or Hanging Lake. Eosine was also detected in the West Fork of Deadhorse Creek immediately upstream of the confluence with the East Fork (HL005). All sampling stations downstream of this point in Deadhorse Creek (HL006, HL007, and HL008) also had positive eosine detections. This could have been the result of both the surface flow from the West Fork of Deadhorse Creek and the groundwater resurgences that sustain Hanging Lake in the East Fork of Deadhorse Creek.

RWT dye introduced into the East Fork of Deadhorse Creek was detected in French Creek just upstream of its confluence with the Colorado River in Glenwood Canyon. This detection is solely the result of groundwater flow as the East Fork of Deadhorse Creek is an entirely different topographic basin to the west of French Creek and there is no surface connection between the two drainages. Interestingly, despite the fact that the East Fork of Deadhorse Creek drains directly into Hanging Lake over Bridal Veil Falls, no RWT was detected in Hanging Lake or any of the sampling stations further downstream in Deadhorse Creek.

Figure 2. Positive dye detections from dye introductions made in September of 2021. Arrows indicate a groundwater connection between the dye introduction locations and sampling stations.



The eosine detections below Spouting Rock and in Hanging Lake clearly show that some of the water in the lake originates in the upper reaches of the West Fork of Deadhorse Creek. There is no surface connection between the West Fork of Deadhorse Creek and Hanging Lake, proving that this connection is through the groundwater system via losing reaches in the West Fork.

Considering the time of year these traces were conducted (just before winter) and the dry conditions under which the dye introductions were made, the 2021 traces also prove that at least some of the source water supplying Hanging Lake moves rapidly through the groundwater system when adequate flow is present. It has been theorized that the massive travertine deposits in Hanging Lake could only be achieved if the source water was underground for a very long time and at great depth. It was also thought the water in Hanging Lake could be upwelling from hypogenic origin. Results from the dye traces conducted in 2021 show rapid groundwater flow indicative of intimate connections between surface drainages on the White River Plateau and the groundwater that sustains Hanging Lake.

Planned Work for 2022

Results from the 2021 dye traces have answered some questions, but have also left much to be discovered. We now know that water in Hanging Lake comes from the upper reaches of the West Fork of Deadhorse Creek, but where exactly are the major losing points in the stream? Are there other losing streams or karst features that contribute water to Hanging Lake? Where does the water from the West Fork resurface in the East Fork to supply Hanging Lake? What are groundwater travel times to Hanging Lake in summer when surface streams flow after precipitation events?

OUL staff will make a second field visit in the summer of 2022 to conduct more hydrological investigations. Points of interest for further investigation include the large sinks located between the West Fork of Deadhorse Creek and Grizzley Creek. These sinks, one of which is a half mile long, will fill with water and subsequently drain quickly, but they are closed depressions. Where does this water go? With the help of Colorado cavers, OUL staff also plan to focus field work on the hydrology of the canyon upstream of Hanging Lake. Study of these karst features, along with additional tracing work that can better determine groundwater travel times, will help further explain the scope and complexity of Hanging Lake's recharge area, as well as aid in understanding what effects the Grizzley Creek Fire may have on Hanging Lake.